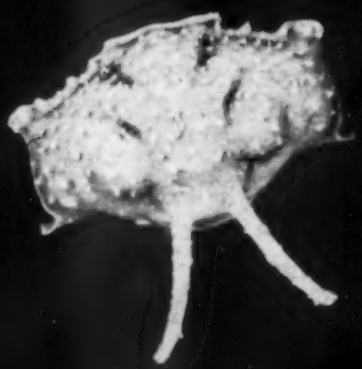
The Earth Science DIGEST



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A magazine devoted to the geological sciences

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QUAKES IN ASIA CAUSE UNITED STATES WATER WELLS TO FLUCTUATE

WASHINGTON, Dec. 28 — A severe earthquake such as the one that was felt over much of southern Asia last August will cause the water level in some wells in the United States to fluctuate, hydrologists of the Geological Survey, United States Department of the Interior, reported today, following an examination of charts from wells in the San Antonio area, Texas, and in Florida.

Automatic water-stage recorders on wells penetrating the Edwards limestone in San Antonio recorded the quake much as instruments designed for that special purpose (seismographs) might do. But the Survey recorders operate with a pen and clock mechanism which produces a graph of the water level as determined by a float device. There is no connection with movements in solid rock such as quake recorders ordinarily pick up.

Yet on two water-level recorders near San Antonio, one of them 4½ miles northeast of the courthouse at Beverly Lodges and the second on a well north of Kelly Air Force Base, telltale fluctuations were noted. In one, the level was recorded at 66.8 feet below the surface before quake time. It rose to 65.8 feet and then dropped to 68.1 feet. After an hour and 45 minutes it returned to normal.

In Florida, H. H. Cooper, Jr., a Survey district engineer, reports that he was present at one of the wells in Hillsborough County when the water level there began to fluctuate. It was rising and falling several hundredths of a foot, he noticed, but attributed this to his having disturbed the well-float. However, while he waited for the motion to subside so that he could set the pen, the fluctuation increased in amplitude to as much as a foot.

He still did not attribute the action to an earthquake, but timed the period of oscillation out of curiosity. The following day when he changed the charts on other wells he became certain that the fluctuations were caused by an earthquake and then learned that there had been one of unusual severity in Asia at the time shown on his records.

This is only one of many instances of such water-level fluctuations occurring as the result of an earthquake, but it is the first time such a marked effect has been noted from a quake at such a distance.

For a recent issue of **Economic Geology**, Garald G. Parker and V. T. Stringfield wrote a paper on the "Effects of earthquakes, trains, tides, winds, and atmospheric pressure changes on water in the geologic formations of southern Florida." They presented and discussed some unusual fluctuations of water level in the permeable limestone aquifers of southern Florida, observed while a hurricane passed over the Gulf Coast, together with other unusual fluctuations that resulted from numerous earthquakes in many parts of the world. The recorder charts show the approximate time that shock waves arrive and reflect their magnitude, they said, adding, "for some of the weaker shocks, especially, the magnitude is probably dampened out by frictional resistance within the recorder itself, or between the float in the well and the well casing, so that the record is not a true representation of the actual water-level fluctuation."

In one well in Miami, they reported, passing trains cause the water in the well to rise; then as the train passes, the level declines to normal. Long, heavy freight trains cause the largest fluctuations, some as great as 0.045 foot in this particular well. The answer: compression effects caused by the weight of the passing train upon an elastic aquifer. Such fluctuations have been recorded in other parts of the country as well.

EVIDENCE FOR A PRIMITIVE HOMOGENEOUS EARTH

HAROLD C. UREY
University of Chicago

[The following are excerpts from the address of Dr. Harold C. Urey, Institute for Nuclear Studies, University of Chicago, given in the Special Session of the 63rd annual meeting of the Geological Society of America.]

Ever since Copernicus enunciated the principle that the earth moved about the sun, men have wondered about the origin of the solar system and some have presented cosmological theories in regard to it. As one looks over these theories and then attempts to accumulate scientific evidence relative to the process he is more and more impressed with the magnitude of the problems presented. In fact all the details of our modern science developed in the twentieth cetnury are needed to unravel the problem and indeed it may well be that all the science of the next century will be required as well. It becomes evident that not only astronomy but physics, chemistry, geology and even biology are required for an adequate presentation of facts and conclusions. Moreover, students of each phase of the subject of necessity must try to understand the contributions of not only his own science but those of other sciences as well. It is a complicated subject and a most fascinating one.

During recent years new attempts have been made to reconstruct the series of events which lead to the present solar system. Whipple, Bok, Spitzer, Kuiper and V. Weizsacker and others have made contributions to the subject. All assume that in one way or another the planets accumulated from a cloud of solid particles suspended in a gas. This dust cloud was acquired by the sun in some way or originated with the sun itself. The planets accumulated from the dust, and the gas was mostly lost, almost completely by the terrestrial planets and partly by the major planets. The conditions imposed by the structure of the solar system are well known. The planets and their satellites with a few exceptions, e. g. Phoebus of Mars and Triton of Uranus, move eastward around the sun, the planes of their orbits and those of their satellites with few exceptions, e. g. Triton, lie within small angles of the ecliptic. The planets usually rotate eastward as well with small angles relative to the plane of the ecliptic with the exception of Uranus whose pole is inclined by 97° from the pole of the ecliptic. The angular momentum of the sun is only a small fraction of that of the planets. The Titius-Bode law for the distances of the planets from the sun is only an approximate law but still it is significant. Astronomers have attempted to account for these facts.

It is the purpose of the present paper to present a discussion of a more limited kind relative to the

origin of the terrestrial planets. There is considerable evidence, chemical, physical, geological and astronomical indicating that the earth and other terrestrial planets were more nearly uniform mixtures of iron-nickel alloy and silicates of the types observed in meteorites and that the iron-nickel alloy phase has moved and is even now moving toward the center of the earth to form the large core which extends some 3400 kilometers in radius. In the discussion it is assumed that the planets accumulated from a dust cloud through the intermediary formation of planetesimals.

After what is estimated to be about 3×10^9 years, much of the evidence in regard to the process through which the solar system evolved has disappeared. There appears to be no part of the surface of the earth that could be regarded as part of its primordial surface. It has been completely modified by water, air, and living organisms, as well as volcanic and plutonic activities generally. Of course, the earth did not evolve as a single member of the solar system, and we do have a rather distant access to other members — the terrestrial, minor and major planets. The moon is the nearest planetary object to us, and the only one upon which details of its surface can be observed. Meteorites come to the earth and give us information in regard to small objects which are describing circum-solar orbits. Mars is more distant, but it is possible to see surface markings on the planet. Venus is covered with dense clouds, probably dust suspended in carbon dioxide gas. Mercury is so close to the sun that it is difficult to observe accurately. The major planets are very different in structure from the earth, being much larger, less dense and having higher masses. Nevertheless, the properties of the planets have been determined in a variety of ways, and do give information in regard to the past history of the solar system.

The primitive structure of the earth and other terrestrial planets

Mars is a planet which has a mass 0.1069 of the mass of the earth, as has been determined recently by Rabe from the perturbations of the minor planet Eros. The radius of this planet is usually reported to be 0.532 of the radius of the earth. However, approximately 25 years ago Trumpler and Wright showed that Mars has a substantial atmosphere, perhaps 75 kilometers thick and hence that the radius of the planet generally accepted is too large. Trumpler studied the motion of the markings of the surface of the planet, and from the positions of these markings relative to the center of the planet he was able to measure the radius of the planet. He found the radius to be 0.521, and this radius should be that of the surface of the planet and independent of its atmosphere. Thus an attempt was made at least to avoid the errors due to the fairly thick atmosphere which carries dust clouds and which made it difficult to determine the diameter of the planet.

A rotating planet develops a bulge at the equator due to the centrifugal force of rotation, and if the planet behaves as a liquid it is possible to calculate how high the bulge should be. This was done by Claireau two centuries ago, and he developed a relationship between the distribution of mass within the planet and the oblateness of the planet, the oblateness being the difference

in the equatorial and polar radii divided by the radius. The assumptions involve only the assumption that the planet takes the shape expected for a liquid in hydrodynamic equilibrium, and it must be remembered that solids in large masses flow sufficiently to accommodate themselves to this hydrodynamic shape.

These calculations also enable us to estimate the uncompressed density of Mars as 3.96. This density is higher than that of rocks on the surface of the earth or the rocky material of meteorites, and indicates that Mars must contain about 30% of iron-nickel alloy as that found in meteoric bodies falling on the earth. It would thus appear that Mars is able to contribute the item that this planet was formed and has remained a nearly uniform mixture of 30% iron phase and 70% silicate phase. The earth, on the other hand has an extensive iron core of high density extending, according to seismological studies, to about 0.54 of the whole radius of the earth, or to 2900 kilometers below the surface of the earth. Iron-nickel alloy and silicate rocks are falling on the earth at the present time in the form of meteorites, and the evidence in regard to Mars indicates that the entire planet is built up of material of this kind which is even now nearly uniformly mixed.

The moon is the nearest planet to the earth and it is the only one for which it is possible to study the surface markings in accurate detail. It is true that a chemist would like very much to have a few samples of its surface, and undoubtedly the knowledge that could be gained in such ways would be enormous, but a study of the surface of the planet shows that some information in regard to the chemical composition can be secured even from a distance of 384,000 kilometers. It is not possible to say much that is completely new about the surface of the moon. For over 50 years an argument has gone on continuously in regard to the fundamental character of the craters on the moon, there having been two schools of thought, the one maintaining that the craters are volcanic in origin and the other that they are due to the collision of meteoric bodies or planetesimals with the surface of the moon. A really definite work in regard to this has been published recently by R. B. Baldwin, ('The Face of the Moon', University of Chicago Press, 1949,) shows that the larger craters of the moon and some of its seas are certainly the result of explosions produced by collisions of planetesimals with the surface of the moon. There are of course small craters on the moon which are undoubtedly due to volcanic effects, but what Baldwin shows is that the large, gross features are due to the collision with planetesimals. He supports this conclusion with quantitative studies of the dimensions of these craters and compares them with meteoric craters on the earth and craters produced by other explosions of an earthly character. Once the conclusion is accepted that these craters are to a great extent due to such collisions, great progress can be made in understanding the features of the moon.

The surface of the moon was produced before geological history began, for otherwise the collision of planetesimals should also have occurred with the earth in very great numbers, and because of the much greater explosive effect expected from objects hitting the earth, amounting to 14,000 small calories per gram, the geological

record of the earth would have been substantially destroyed had these craters been produced at a uniform rate through geological time. We conclude therefore that in the face of the moon we see a fossil record of the time at the end of the formation of the moon and probably this time was the same as that of the end of the formation of the earth, and in fact the time at the end of the formation of the entire solar system. This leads to the conclusion that at the terminal stage of the formation of the planets they were accumulating from smaller planetesimals. This conclusion makes the surface of the moon a truly fascinating subject for study, and makes it of prime importance from the standpoint of observational data relative to the origin of the solar system.

In 1893 C. K. Gilbert, an American geologist, pointed out that all through the center of the moon's disk there were a series of radiating ridges and grooves which, when extended backward, intersected in the region of Mare Imbrium. The conclusion was drawn by Baldwin that an enormous explosion took place in the center of this sea and scattered debris over the entire center of the moon's disk 1000 kilometers and more away. These ridges and grooves have been described by many writers. The grooves have been ascribed to the effects of iron-nickel alloy objects ploughing through the surface of the moon. The application of ballistic formulae indicates that it would require objects of a kilometer or more in radius to produce these grooves and that the back pressures on objects moving through the surface of the moon at the speeds required, namely, at about the circum-surface velocity of an object on the moon of 1.60 kilometers per second, would be 30,000 kilograms per square centimeter, and would thus exceed the crushing strength of basalt by many times. It seems that these grooves must have been ploughed out by iron-nickel alloy objects. The Alpine Valley also appears to have been produced by a missile from this same explosion. It is 130 kilometers long and about 10 kilometers wide. But other objects from this explosion have produced long radiating ridges through the region of the Apennine Mountains and the Haemus Mountains. The Carpathian Mountains on the southeast side of the Imbrium sea are also of this same kind. It would appear that these ridges were made of materials having perhaps a silicate composition, and thus the indication is that a rather large object hit the moon which contained both iron-nickel alloy and silicate. Again at the terminal stage of the formation of a planetary body both of the types of the materials that are found in meteoric bodies were arriving on the surface of this planet. These grooves are not unique on the moon, for the Rheita Valley south of Mare Nectaris is approximately 300 kilometers long, some 15 and more kilometers wide and perhaps about 2 kilometers deep. The direction of this valley does not point toward Mare Imbrium, and must have been produced by some other collision with the moon, and again must indicate the presence of iron-nickel alloy arriving on its surface. Other valleys of this kind are observed.

The fact that Mars is probably a planet of uniform chemical composition consisting of a mixture of iron-nickel alloy and silicate rocks, and the fact that iron-nickel alloy fell on the surface of the moon at the terminal stage of

its formation, do not necessarily prove that the earth was formed of a grossly uniform mixture of iron-nickel alloy and silicate. We turn to the earth for evidence in regard to its early chemical composition. There is rather direct evidence of native iron in the outer parts of the earth. On Disco Island on the west coast of Greenland there is a basaltic flow which contains large bodies of native iron. This native iron contains some 2% of nickel and small amounts of the platinum metals. Both the nickel and the platinum metals are not characteristic of the usual iron ore bodies found on the surface of the earth, and the iron-nickel alloy is mixed intimately with the basaltic material. The general weight of opinion appears to be that the basalt carrying the native iron flowed from the interior of the earth, probably below the Mohorovicic discontinuity from 33 kilometers below the surface of the earth, as it seems possible and perhaps probable that other large basaltic flows have done. The evidence seems good that this is the case, but recent experiments made on the abundance of the oxygen 18 content of igneous rocks by Silverman (Univ. of Chicago, 1950) working in the author's laboratories, show distinct variations in the abundance of the oxygen isotopes in igneous rocks and sedimentary and metamorphosed rocks. Briefly, oxygen 18 is less abundant in those igneous rocks which from all other geological evidence have come from deep within the earth's crust than it is in metamorphosed and sedimentary rocks. The Disco Island basalt lies securely among those rocks, showing an isotopic composition characteristic of deep-seated origin, and this isotopic composition is precisely the same as that of the oxygen of stone meteorites. It thus appears that the Disco Island basalt came from deep in the earth's crust and presents us with a sample of native iron which still lies below the crustal area of the earth. Thus even though the surface layers of the earth have been modified by water, erosion and by volcanic activity of the earth, we have evidence that indicates that its primeval surface also contained iron-nickel alloy mixed with its silicates.

A study of seismology has given us important information in regard to the interior of the earth. The so-called crust of the earth is approximately 30 to 50 kilometers thick. There appears to be a very sharp boundary approximately 33 kilometers below the mean surface of the earth, known as the Mohorovicic discontinuity. Above this layer the general composition of the earth appears to be about that of basalt, while below this layer the silicate rocks are believed to be approximately that of olivine. There is a difference in density of these two kinds of rocks of about 0.3, the basalts being somewhat lighter and containing increased amounts of the radioactive elements; while the olivines are approximately magnesium ortho silicate with some of the magnesium replaced by ferrous iron. Somewhere in the neighborhood of 400 to 1000 kilometers below the surface of the earth there is another gradual change in the chemical composition. This is indicated by an increased velocity of the seismic waves, and attempts that have been made to study the density of the earth as a function of depth always indicate that somewhere in this neighborhood there is a marked increase in the density of the earth, amounting to approximately

0.5 grams per cubic centimeter. The evidence in regard to the change in composition which occurs at this point is not clear, but one of the obvious suggestions which can be made is that the increase in density is principally due to an admixture of iron with the silicate phase. The evidence which has been presented thus far would indicate that this is a reasonable assumption for the earth. However, the increased density due to the admixture of iron makes it somewhat difficult to account for the increased velocity of the seismic waves below this level. But as the problem of vibration of solid bodies consisting of heterogeneous mixtures is an exceedingly complex one, very approximately understood, and as we have but little information in regard to the properties of substances at the high pressures existing in this region, it seems possible to assume that the increased density is indeed due to the presence of iron mixed with the silicate materials of the earth.

We turn to other evidence in regard to the subject; namely, that from astronomical observations. Over the past 25 centuries men have observed the time at which eclipses of the sun and moon have occurred, and it is possible to calculate from modern observations of the motion of the sun and moon in the heavens the time at which such eclipses should have occurred; and it is found that exact agreement between the time of an eclipse and the astronomical calculations does not exist. The data in regard to this have been reviewed by two men in particular — Fotheringham and, later, de Sitter, and from this we must conclude that the moon and the sun move forward at a faster angular velocity than is to be expected on the basis of the gravitational theory for the motion of these bodies (the motion of the sun of course involves the motion of the earth about the sun). These accelerated motions are referred to as the secular accelerations of the sun and moon. Many attempts have been made to account for these accelerations, and it is generally believed at the present time that they are due to the slowing down effect of the tides on the rotation of the earth. The moon moves away from the sun, but the latter effect is very slight indeed. It is possible to calculate the ratio of the sun and moon in terms of the tidal torques that are exerted on the earth by the sun and moon respectively.

If one introduces into this (Jeffreys) equation the observed secular accelerations of the sun and moon and solves for the ratio of the tidal torques on the earth, one secures a negative quantity, indicating that while the one of these objects slow down the rotation of the earth, the other accelerates it. This of course is impossible, for both should slow down the rotation of the earth. Jeffreys calculated the ratio of these torques, and on the basis of two different assumptions concludes that the torques, as exerted by the moon should be between 3.4 and 5.1 times as great as that of the sun. No agreement with experiment is secured, and Jeffreys states, "that either an unknown cause is producing a secular acceleration of the sun, or that part of the observed value is in error."

If iron exists in the outer parts of the earth it should move toward the center of the earth with a decrease in potential energy, and should thus be a spontaneous process. If one solves for the rate of change of the moment of

inertia of the earth which is required to give agreement between Jeffreys' theory and the observed secular accelerations, one finds that the change in moment of inertia should be sufficient to give an effect half as great as the effect of moon on the earth, and of course opposite in sign, that is, it should cause the earth to increase its frequency of rotation while the moon decreases the speed of rotation, and it is then possible after a very considerable amount of calculation, which however cannot be made exactly, to estimate, that between 4 and 7×10^{10} grams of iron must flow out of the mantle of the earth to the core of the earth per second in order to account for the changing moment of inertia of the earth which will make possible the explanation of this secular acceleration of the sun and moon as due to the combined effects of change in the moment of inertia and tides. But this number of grams of iron per second would produce the entire iron core of the earth, estimated as 1.85×10^{27} grams, in approximately 1 billion years. The age of the earth is estimated at 3 billion years, and hence the iron must be flowing to the core of the earth approximately three times as fast as the average over 3 billion years if the core of the earth was produced since the earth was formed. The evidence from this astronomical phenomenon would indicate that the core of the earth is growing with time and that it was produced during the time since the earth was formed.

The evidence from these various sources indicates that the earth was formed out of planetesimals as perhaps an approximately uniform body consisting of a mixture of iron-nickel alloy and silicate, approximately 45% of the former to 55% of the latter.

It is to be noted that this composition for the earth differs from the estimate for Mars. Also, the radius of Mercury is such that its density, using Rabe's recent value for the mass of Mercury, namely, 0.0543 of the earth, the generally accepted radius of 0.39 of the earth leads to a density of approximately 5, and approximately 63% of iron phase in this composition. Thus further variation in chemical composition within the solar system seems to exist. (The following table estimates the chemical composition of the terrestrial planets, Venus being assumed to be the same as that of the earth.) It thus appears that in the formation of the planets some fractionation process took place which separated the silicate from the iron phase. It happens that there are chemical processes which could volatilize the silicates at a few atmospheres pressure of hydrogen and temperatures of the order of 2000° K. It thus appears that such a fractionation process actually took place. It is not, however, the intention of the writer to go into this chemical discussion at this time.

Folded mountains occur on the earth. They appear to be due to great lateral movements of the earth's crust which fold up the surface of the earth in great folds. During the last approximately 60 million years most of the high mountains of the earth have been produced by this process — the whole Cordillera range of the North and South Americas and the Alps and Himalayas, and such folding of the earth's crust has occurred repeatedly during geological time, the mountains being worn down by water and raised again by such movements of the crust. Many sug-

gestions have been made in regard to the origin of the energy which has produced mountains, but if the core of the earth is being produced by processes which transfer iron from high in the outer regions of the earth to the core, this may be an important source of energy for these processes. In fact, they appear to be far too energetic rather than lacking in sufficient energy, and it may indeed be fortunate that there is a layer some 400 kilometers thick which protects us from the vast movements of the interior of the earth to a partial degree and makes the effects at the surface of the earth only as great as they are. The moon has no folded mountains, and it certainly has no iron core, though iron was falling on the moon's surface at the terminal stage of its formation. Iron phase does not form an important fraction of the body of the moon, since its mean density is only that of the stone meteorites, namely, about 3.3. This difference in structure of the moon and the earth would appear to be the most obvious reason for the difference in the behavior in the crust of the moon and that of the earth. So far as the other planets are concerned, we have no certain knowledge in regard to the formation of mountains at all.

The Early Atmosphere of the Earth

The conclusions drawn above in regard to the original structure of the earth are more or less controversial, and many may disagree with them, but it seems safe to conclude that some iron arrived on the surface of the earth in the closing stage of the formation of the earth, and if metallic iron was present in only small amounts, surely ferrous oxide was a constituent of the planetesimals arriving on the earth. In the second place, some water must have been present in the primordial atmosphere of the earth during its latter stages of formation. Perhaps all the water of the present oceans was not present as a hot steamy atmosphere, but at least some must have been present, for otherwise water would not have dissolved into the rocks of the earth, it being impossible to dissolve a gas into a solid or liquid phase without having some pressure of the gas over that phase. Thus we can very certainly conclude that water and iron were present at this time, and if this is the case then one of the most certain conclusions that can be drawn is that hydrogen was also present in large amounts, for iron and water or ferrous oxide and water react to give hydrogen and iron oxides. The equilibrium constant favors the formation of hydrogen at low temperatures to a very great degree, and even at temperatures of 1000° the equilibrium constant is in the neighborhood of unity, so that equal amounts of hydrogen and water should be present in the atmosphere.

Our picture, then, of the changing situation in the early stages of the earth is as follows: Hydrogen is first present in large amounts but steadily escapes from the planet. In the first stages ammonia and methane are present. As the hydrogen escapes, compounds of carbon containing oxygen and nitrogen will become stable — the alcohols, the amines, and amino acids, the aldehydes, the organic acids. Thus we see that as the hydrogen escapes, carbon and nitrogen and oxygen will appear in many complex organic compounds.

As further hydrogen escapes and the atmosphere becomes oxidizing, water in the high atmosphere of the earth is photochemically converted into hydrogen and oxygen and the hydrogen will escape while the oxygen will not, and thus the whole atmosphere would be converted to an oxidizing one. Under these conditions methane would be converted to carbon dioxide and ammonia to nitrogen, and all organic compounds would disappear into these compounds and water. Thermodynamic calculations show that carbon dioxide would react with silicates to form calcium and magnesium and other carbonates and silicon dioxide until the pressure of carbon dioxide decreased to approximately its present value. This condition would be maintained from this time on. The free oxygen, when all of these easily oxidizable substances have disappeared, would attack the ferrous oxide of the surface of the earth, converting it to ferric oxide. A thoroughly oxidized situation would result. Of course this is not the situation that obtains on the earth, for we have quantities of carbon and carbon compounds in the surface layers of the earth.

But the course of events which we have outlined would be precisely those which would be favorable to the evolution of life at the stage of development between the strongly reducing and the strongly oxidizing conditions. An enormous quantity of organic substances should exist on the earth. It is not possible to describe in detail how life evolved, but if we try to imagine favorable conditions for this, this intermediate stage would appear to be the most favorable that anyone has suggested. It might be remarked that if most of the oceans were incorporated into the crust of the earth at this time, the concentration of organic substances in the remaining water on the surface of the earth would be larger than if all of the oceans were on the earth at the present time, and in some way the concentration of organic substances must have occurred if small bodies of organic substances were to organize themselves into primitive living organisms.

It is of interest to observe the conditions that exist on other planets. The simplest to interpret is that of Venus, which contains a thick atmosphere in which carbon dioxide in large quantities has been detected. The atmosphere is dusty, which gives the planet its characteristic white color, and there appears to be no water in the atmosphere.

However, it is to be assumed that the early atmosphere of Venus must have been like that of the earth, probably contained water, hydrogen, methane and nitrogen, perhaps not in the same proportions. Thus if there was too little water and the hydrogen escaped from Venus, as postulated above for the earth, the oxygen would consume all of the methane and produce carbon dioxide and carbon monoxide, and if at some stage all of the water were consumed by this process the process would stop. At ordinary temperatures all of the carbon monoxide would be converted to carbon dioxide and carbone, and hence the atmosphere of Venus is completely understood providing the amount of water on that planet at the closing stage of its formation was much smaller than that of the earth.

Mars has a substantial atmosphere, and it is not possible to recognize those constituents of an atmosphere which do not absorb

light. We do not know whether Mars, or in fact Venus either, contains nitrogen or argon in its atmosphere, but the atmosphere of Mars is known to contain small amounts of carbon dioxide. Interestingly enough the surface pressure of carbon dioxide on the planet is very closely the same as that of the earth, a situation to be expected providing the equilibrium between carbon dioxide and silicates to form carbonates and silicon dioxide is attained on the planet as it is approximately on earth. The water in the atmosphere of the planet is very small in amount.

Mars has long been supposed to have some form of life upon it, and Kuiper's experiments indicate strongly that primitive forms of plant life are available. It is difficult to understand how life might have evolved in almost the total absence of water, though it might maintain itself under the very hard conditions that obtain on the planet, i. e., the low concentration of water and the unfavorable temperatures. It thus seems possible that Mars may have had a larger atmosphere of water in the past, which has been lost by the photochemical reaction mentioned above in the high atmosphere, and then the difficult question arises as to why it should happen that after 3 billion years, roughly, since the origin of the solar system just a very small amount of water is left. One wonders why it did not all disappear, as in the case of Venus. This is a question which cannot be answered with any confidence at the present time, but in another connection the writer has pointed out that with the arrival of meteoric dust upon the planets some other constituents may be arriving as well, constituents which are much more volatile than the silicate particles which quite certainly arrive in the high atmosphere of the planet earth and presumably in the atmosphere of Mars. Among such constituents water should arrive, and it may just be that the present small amount of water on the planet is a steady concentration, determined by the rate of arrival on the planet and the rate of photochemical dissociation and loss from the planet. Volcanic activity does not appear to be a very probable source of water since no high mountains have been observed on Mars.

Mercury is too small a planet to hold an atmosphere at this distance from the sun, and so far as we know it has no atmosphere.

It has been the purpose of this discussion to review certain features in regard to the early history of the terrestrial planets, and hence no consideration has been given to the major planets, which have quite a different structure. The discussion is not complete because of the extensive calculations which must be given in detail to substantiate the statements made.

Yale Gets Grant For Radiocarbon Dating Lab

NEW YORK, Jan. 18 (Science Service) — A laboratory for radiocarbon dating archaeological and recent geological specimens is to be established at Yale University with a Rockefeller Foundation grant of $42,500.

The new Yale laboratory will establish a second center for making determinations of radiocarbon 14 activity in specimens of organic origin connected with the early history of man and the recent geological history of the earth and archaeological and prehistorical discoveries.

PENROSE MEDAL GOES TO A CANADIAN

Dr. Morley Evans Wilson, Geological Survey of Canada, received the coveted Penrose medal of the Geological Society of America at a smoker held in the Presidential Ballroom of the Hotel Statler, Washington, D. C., during the Society's 63rd annual meeting. The presentation was made by Dr. John Willis Ambrose of Queens University, Kingston, Ontario.

The Penrose medal was established in March 1927 by the late R. A. F. Penrose, Jr., "in recognition of eminent research in pure geology" and of "outstanding original contributions or achievements which mark a decided advance in the science of geology." Dr. Wilson is the twenty-first recipient.

Delivering the citation Dr. Ambrose stated that the medalist has devoted a lifetime to studying the geology of the Pre-Cambrian Shield, the very ancient rocks of eastern Canada. He was the first to demonstrate that it is possible to unravel the complexities of structure and stratigraphy over any appreciable area. Before that it was generally believed that ordinary stratigraphic methods would be of no avail.

"In 1932," said Dr. Ambrose, "Wilson, after distinguished work in Pre-Cambrian terranes in many parts of Quebec and Ontario, began his great studies of the Archean complex around Noranda, Que. (These are earth's oldest known rocks). He showed there, for the first time, how internal primary features of lavas, such as pillows, flow structure, contraction joints, contacts, could be used to untangle the stratigraphic sequence, the structure complexities, and the geological history of the ancient rocks.

"The most painstaking work, extended over a period of five years, was necessary to complete study of an area of less than 30 square miles. However, his report, 'The Noranda Area,' when it was finished was nothing less than a revelation to Pre-Cambrian geologists.

"Knowledge of the Archean in Canada has, as a direct consequence of Wilson's work, expanded in the last 15 years with astonishing rapidity. For example, areas in the gold and gold-copper producing belt that extends from Matachawan in Ontario 150 miles eastward to Pershing township in Quebec; around Little Long Lac and Red Lake, Ont., in southeastern and north central Manitoba; and Yellowknife in the Northwest Territories, to mention only a few, are yielding their secrets grudgingly but surely. Wilson pioneered the field and showed the way to those who followed."

In his response Dr. Wilson pointed out the vast amount of geological work still remaining to be accomplished in the Canadian Pre-Cambrian Shield. "We know that this is largely a region of greatly denuded mountain-built rocks," he said, "and that it is in such regions that ore deposits derived from igneous rocks are usually found.

"We also know that the emplacement, form, and extent of most ore deposits are controlled by the structure of the formations in which they occur, and that there are criteria by which these structures can be determined."

Probably not more than a few thousand square miles of territory underlain by Archean rocks in the whole of the Canadian Shield have been mapped structurally, he said, commenting that there are immense areas underlain by rocks of both Early and Late Pre-Cambrian age that have not been mapped at all. He reminded his audience that it was the early explorations of Low in the Labrador peninsula that led to a knowledge and the present development of iron ore deposits in Ungava and Labrador.

Dr. Wilson took his bachelor's degree work at the University of Toronto, and received his doctorate from Yale in 1912. He has been associated with the Canadian Geological Survey since 1907.

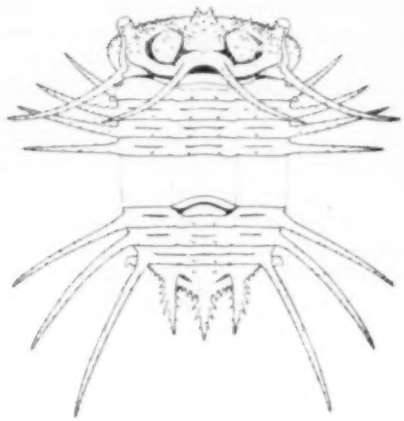
"NEW" TRILOBITES DESCRIBED

HERBERT B. NICHOLS
U. S. Geological Survey

More order has been brought out of chaos for "trilobite hounds," fossil hunters specializing in a group of marine animals that inhabited ancient Paleozoic seas, by two papers presented at the 42nd annual meeting of the Paleontological Society of America.

Trilobites were known as "petrified butterflies" or "flat fish" in the days before they were studied scientifically. So-called because their lobster-like outer skeleton or casing can be divided into three lobes either lengthwise or crosswise, trilobites ranged from pinhead size to some of the giants that grew to be 27 inches long. They have been extinct for more than 200,000,000 years, but because they form such unusual looking "three-lobed stones" where they have weathered out of limestone, (particularly of the Cambrian and Ordovician periods of more than 350,000,000 years ago) they have excited the curiosity of laymen and scientists alike and started many a mounting interest in geology.

Known from quarries and limestone exposures in close proximity to some of our larger cities as well as more remote regions, trilobites went through a moulting process in which their outer skeleton was shed in much the same manner as more modern arthropods (articulate animals with jointed limbs like the insects, spiders, lobsters and crabs). Growth proceeded to a point where the animal became too large for its shell, whereupon the creature

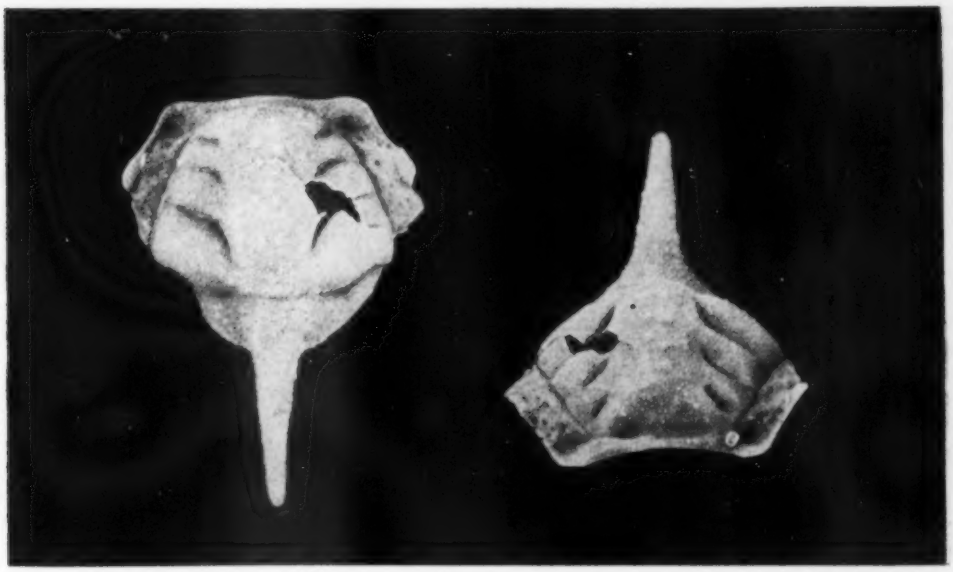


A reconstruction of Ceratocephala (x1½), *which was made in part from the two photographs reproduced on this month's cover of the Earth Science Digest. Courtesy of H. B. Whittington.*

"burst its buttons" and crawled out of the old case. Until a new one formed and hardened, it was in a "soft-shelled" condition like soft-shelled crabs before the thin chitinous skin hardens. As might be expected a large number of trilobite fossils are made up of these cast-off exoskeletons or portions of them.

To gain a knowledge of the growth stages these ancient animals passed through and perhaps throw some light on their relationship to each other and to other animals and to the whole picture of evolution, is a goal sought by modern paleontologists.

In describing two middle Ordovician trilobites Harry B. Whittington Associate Professor of Geology, Harvard University, showed lan-



Dorsal (left) and anterior (right) views of Holia Cranidium (x4).
Courtesy of H. B. Whittington.

tern slides of one species of Ceratocephala that is now completely known, with its various developmental stages reconstructed. This trilobite was very spiny which suggests that it was mostly a floating or swimming species.

Holia was the other trilobite described, previously known from the Kimmswick limestone of Missouri and Illinois. This one had a tail or "pygidium" (like the telson the lobster uses to propel itself through the water) with two long, upcurved spines. The cranidia or central portion of the creature's head was also spiny in the young stages, but as the adults increased in size the spines degenerated to mere tubercles.

Prof. Whittington told the meeting that both species selected for discussion are part of a collection of some forty others obtained from limestones of Ordovician age which outcrop near Strasburg, Virginia. They were deposited about 350,000,000 years ago in the shallow sea which then covered this area.

"Included in the mud and lime deposits were the shells of invertebrate animals living there," he said. "The trilobites, creatures akin to the kingcrab of our present-day shores, and having a similar shell, were important among these animals.

"In some way which we do not fully understand, the shells of the trilobites and other groups of animals were replaced by silica after they had been enclosed in the limestone rock. It may be that the silica for this replacement comes from the thin but widespread beds of volcanic ash that once interbedded with the limestone. Today when a block of this rock is dissolved in hydrochloric acid, the silica shells are not attacked by acid but are freed completely from the enclosing rock. At least half a ton of limestone has

been dissolved in this way and a large collection obtained.

"Trilobites are not living today," he said, but "a great variety lived in this ancient sea in Virginia, none more than 2 or 3 inches in length, with the head, segmented body and tail. The beautifully preserved shells show such details as the many lenses of compound eyes, the granules and pits of the ornament, and sometimes long, delicate spines that assisted the creatures to float. Because the shell is free from the rock, the inside surface can be examined, and processes for attachment of muscles and articulation of parts of the shell observed. Even fine canals which pierced the shell, and from which a hair may have protruded, are preserved.

"Not only are the adult trilobite shells contained in the rock, but those of young ones also, from the first circular shell the size of a pin-head, upwards. These are just as marvellously preserved, and enable the development of each species to be studied in detail. Trilobites moulted as they increased in size, casting off the old shell, and many of these fossils must be these moults, drifted over the ancient sea-floor. Clearly they did not drift far, for they are in many cases undamaged and almost always undistorted.

"Study of these fossils reveals the structure of the extinct trilobites shell in great detail, and may enable us to place this group more exactly in the animal kingdom." An understanding of evolution in trilobites" may add to our reconstruction of the evolutionary picture as a whole," he concluded.

Reuben J. Ross Jr., Assistant Professor of Geology at Wesleyan University told the meeting about studies of trilobite fauna of Lower Ordovician age (Garden City formation from northeastern Utah) that have been conducted during the past five years at Peabody Museum, Yale University and at Wesleyan. More than 85 species have been identified, he said, most of them new. These fall into 12 faunal zones which he asserted can be recognized throughout a large part of the Cordillerran ranges with many of the genera having their counterparts in correlative strata in other continents.

Professor Ross described what he believes to be a previously unrecognized type of protaspid (or smallest trilobite larval stage) almost ovoid in shape. They bear three pairs of prominent spines on the carapace or head portion and appear to be partially enrolled individuals. They lack signs of transverse segmentation although the head is faintly divided longitudinally into an axial and two lateral portios. On the smallest specimen, less than a quarter of an inch in length, the facial sutures are already developed, he said, indicating that the free cheeks or side pieces of the head region bearing the eye-facets were already functional.

Many paleontologists believe that in some groups a sightless condition was primitive while in other groups blindness developed secondarily. It has been shown that in some species all gradations of degeneration from forms with good eyes to those without any, can be found. Some have a pair of simple eyes, with one lens apiece, and some a third, centrally located eye, or "oiellus". Throughout one great family their large conspicuous eyes are of a type which is usually called "compound" but which might better be labelled "composite." Each eye is made up of many simple ones, each with its own cornea. This is the sort of eye that most spiders, crabs, etc., possess. Practically

all trilobites with these compound eyes had special provisions for shedding their exoskeletons, for the surficial covering of the eyes had to come off too.

Only the upper surface of trilobites was protected by a tough shell. The under side had but a single plate, located under the central port of the head. The rest was covered only by a thin skin. Like the living armadillos, trilobites would protect their under surface by enrolling themselves. Many died in that position and were well preserved to furnish some of the best available specimens.

CALIFORNIA RARE EARTH FIND OF HIGHEST IMPORTANCE

WASHINGTON, Jan. 16 — Valuable deposits of rare earth minerals newly discovered in southern California by Geological Survey scientists may enable the United States to become largely self sufficient in these elements. The discovery is one of the highest importance, because the United States is at present dependent upon foreign sources for its supply.

The new finds are in San Bernardino County, near the Mountain Pass service station, 35 miles east of Baker, California, on Highway 91, Secretary Chapman said. A vein of rare earths was originally discovered in this area in 1949 on the so-called Birthday claims, and intensive studies of the area were begun shortly thereafter by geologists of the Geological Survey. These studies indicate that an area roughly 6 miles long and 2 miles wide, extending southeast from the original discovery, contains numerous deposits of rare earths, chiefly cerium, lanthanum, neodymium, and praseodium.

The full size and extent of these deposits are still not known, but some of them appear to be very large. D. Foster Hewett, geologist in charge of the field investigations for the Geological Survey, estimates that a single deposit in the area, if it extends to a depth of 100 feet, may contain about 50,000 tons of rare earth bearing minerals.

The rare earths are known most popularly as "flints" used in lamps and pocket lighters, but more important uses are found in such items as arc lamps, tracer bullets, and luminescent shells. Metallurgists have found rare earths of considerable value in alloys of light metals and for improving the quality of some steel. Various chemical compounds of rare earths are used in many industries. Recently it has been found that several of the rare earths are excellent absorbers of slow neutrons, and thus will find important uses in atomic research.

The chief rare earth mineral in the deposits is bastnaesite, a fluocarbonate of the cerium earths. Rare earths constitute about 65 percent of the mineral, and variable quantities of thorium also are present. The bastnaesite is found in veins and bodies of barite-carbonate rock associated with the uncommon types of igneous rocks, shonkinite and syenite.

Most important of the new discoveries are several bodies of barite-bastnaesite rock that appear, from representative samples, to contain from 10 to 40 percent of cerium earths. These ore bodies occur within an area of barite-carbonate rock, approximately 20 acres in extent. Samples from the largest high-grade deposit, which crops out in an area of approximately 90 by 130 feet, show an average rare earth content of about 20

percent. This deposit, which has not yet been prospected, is about 4,000 feet southeast of the original Birthday claims discovery. A smaller body of high-grade rock crops out about 3,000 feet southeast of the Birthday claims. Both of these bodies are within claims reported to be owned by the Sulphide Queen Mining Company.

In addition to the high-grade bodies, local areas in the barite-carbonate rock about 6 acres in extent contain 5 to 16 percent bastnaesite, or from 2 to 8 per cent rare earths. Barite generally averages around 20 percent of the barite-carbonate rock, but locally constitutes from 50 to 90 percent of the rock.

Numerous veins similar to those on the Birthday claims also have been found within the belt extending southeast from the original discovery.

Although the rare earth content alone makes the discovery spectacular, Secretary Chapman said, barite is also a valuable constitutent of the deposits. Barite is widely used by the petroleum industry as a constituent of heavy drilling muds, and it has many other important industrial and chemical uses. If the large barite-carbonate rock area extends to a depth of 100 feet, it should contain some hundreds of thousands of tons of barite.

The Geological Survey will continue intensive studies of the new deposits, Secretary Chapman said. Under present plans, the deposits will be explored by drilling to determine their extent, depth, grade, and geologic relations.

The rare earths now are obtained from the mineral monazite, a phosphate of the cerium earths. Prior to about 1910, this country produced enough monazite from the stream gravels of the Carolinas to satisfy the then small world needs. The discovery of richer beach deposits of monazite in foreign countries, chiefly Brazil and India, forced domestic mines to close shortly thereafter. Recently developed uses for rare earth elements have increased the national requirements faster than it has been possible to increase imports.

CONFERENCE ON THE TEACHING OF EARTH SCIENCE IN THE SECONDARY SCHOOLS

A conference on the Teaching of Earth Science in the Secondary Schools, sponsored by the Earth Science Institute and the Education Committee of the American Geological Institute, will be held at the Museum for Geographical Exploration of Harvard University on March 16-17, 1951.

PURPOSE: Since the earth sciences embrace much of chemistry, physics, and biology, and since a natural laboratory is available and free in the out-of-doors which the pupils inhabit, the subject of *earth science* provides an adequate, low cost, and culturally advantageous approach to science which should commend itself to many school departments. For these reasons the sponsors of the Conference believe that *earth science* should occupy a far more important place in the curricula of secondary schools than at present. The goal of the present Conference is directed not only to the end of increasing the part of *earth science* in the curricula of junior and senior high schools, but also to an examination of the materials which are best included in such a course.

PROGRAM: Outstanding leaders in the field of *earth science* education are to take part in the program. These include Professor Kirtley Mather of Harvard; Professor Chester R. Longwell of Yale; Professor Mary E. Mrose of the

Salem, Mass. State Teachers College; Dr. John Hall Moss of Franklin and Marshall, Lancaster, Pa.; Dr. Ben Hur Wilson of the Joliet, Illinois public schools; Dr. David Delo of the American Geological Institute; and Mr. Waldo Holcombe of the Brooks School, North Andover, Mass. The value of museum field trips in *earth science* education will be demonstrated in a conducted trip through the University Museum of Harvard by Professor C. Wroe Wolfe of Boston University. The formal program will begin at 1:00 p.m., Friday, March 16 and will close Saturday at 3:00 p.m.

REGISTRATION: Registration is open to all persons interested in the program of the Conference. Invitations to the Conference are being sent to the superintendents of schools and junior and senior high school principals of the New England States; state educational associations; college and university geology departments; state teachers colleges; and to individuals interested in *earth science* education. Registration will be held in the Museum for Geographical Exploration, Divinity St., Cambridge, Mass., on Friday, March 16, 11:00 a.m. to 1:00 p.m.

FINAL ANNOUNCEMENT: A final announcement of the program, with a comprehensive summary of times, speakers, and subjects, will be forwarded about March 1. Final announcements will be sent only to those who indicate their interest by contacting the Chairman of the Conference, Professor C. Wroe Wolfe, Boston University, Boston 15, Mass.

A report based upon the papers and discussion presented at the first Conference on the Teaching of Earth Sciences in the Secondary Schools, held at Boston University on March 17-18, 1950, was published in the May, June, and July 1950 issues of *The Earth Science Digest*, the official publication of the Earth Science Institute.

FOLSOM MAN STILL RANKS AS OLD-TIMER

CHICAGO, Dec. 26 (Science Service) — The mysterious ancient American, Folsom man, is an old-timer after all. He lived about 10,000 years ago. Anthropologists, who have found his distinctive stone spear points in diggings over a wide western U. S. area, had a bad scare when the first "atomic calendar" tests of charcoal on his campfires showed a mere 4,000 years of age.

Dr. Willard F. Libby of the University of Chicago's Institute of Nuclear Science made a recount on other material known to have been associated with Folsom man, whose skeletons have never been found. He extracted the radiocarbon from the charred meat within a burned bone from a long extinct species of bison that Dr. E. H. Sellards found associated at Lubbock, Texas, with things that Folsom man once used. The intensity of the exploding carbon atoms gave an age of 9,900 years, with an indefiniteness of 350 years more or less.

The radioactive age tests can be made because cosmic rays from outer space smash nitrogen of the upper air into a radioactive kind of carbon which disintegrates with a half disappearing in 5,600 years. Weakness of radiation measures the antiquity of living matter that uses the carbon.

ORIGIN OF THE TRANSVERSE DRAINAGE OF THE NORTH ATLANTIC SLOPE

How it has come about that many of North America's major rivers on the North Atlantic coast flow southeastward across mountain barrier after mountain barrier of resistant rock on their way to the sea has puzzled geologists for many years. Water does not flow uphill of its own accord and it normally goes around mountain ridges, not through them.

Yet the Potomac, Susquehanna, Schuylkill, Lehigh and Delaware Rivers cut directly across some of the highest uplifts in the Appalachian Mountains. In a paper offered for presentation at the 63rd annual meeting of the Geological Society of America, Dr. Charles W. Carlston of Oberlin College describes the background of this problem and gives his own explanation of how it came about.

"Students of historical geology," he says, "are in general agreement that near the close of the Paleozoic era there were highlands along or near the present Atlantic coastline between New York and Virginia. To the west of these highlands were lowlands and shallow seas. The Appalachian revolution at the close of the Paleozoic era raised high mountains to the west of the old Paleozoic highland. The highest uplifts in the newly formed Appalachians were in the eastern part of the Appalachians between a line running through the present Blue Ridge, South Mountain, Schooley Mountain and the Ramapos on the west, and the coastal plain on the east and southeast.

"Theoretically, streams forming on the uplifted Appalachian mountains should have flowed off to the northwest, or in the opposite direction to the direction of flow of the present major rivers, the Delaware, Lehigh, Schuylkill, Susquehanna and Potomac rivers. These now flow southeastward across mountain barrier after mountain barrier of resistant rock on their way to the sea.

"The problem of the origin of the courses of these rivers across the mountain barriers has interested geologists since 1880. One of the earliest geologists to propose a theory of origin of the transverse stream courses was the late William Morris Davis, the eminent geomorphologist of Harvard University. His theory, published in 1889, was quite complicated but it received general acceptance until 1931 when the late Douglas Johnson, geomorphologist of Columbia University, published 'Stream Sculpture on the Atlantic Slope.' In this book Johnson referred to the highly complex nature of Davis' theory and proposed a new one which accounted for the transverse stream courses in a much simpler fashion.

"He postulated that in Cretaceous time the ridges and valleys of the Appalachians were obliterated by marine waters of the Atlantic which deposited a cover of coastal plain sediments far inland over the Appalachians. When the seas withdrew streams formed upon the coastal plain cover of sand and clay and flowed southeasterly to the sea. These rivers cut down through the coastal plain mantle and found themselves superimposed over the ridges and valleys underlying the costal plain beds.

"The simplicity of the theory gained it many adherents, although a number of geologists could find no evidence in present outcrops of Cretaceous coastal plain sediments that these beds ever extended so far inland. Since publication of Johnson's theory a number of geologists have advanced other theories of origin of the transverse drainage of the Appalachians, but unfortunately such attempts to date have been shown to be in some degree scientifically invalid and have not been widely accepted.

"The present author has found evidence that Davis' earlier theory may be readily simplified and in its new form satisfactorily and simply accounts for the transverse drainage. The difficulties involved in postulating extensive overlap of marine sediments in Cretaceous time thus need no longer concern the geologist since the transverse drainage may be explained without extensive coastal plain overlap.

"The present investigation was begun by an attempt to determine the maximum landward extent of coastal plain beds from the pattern of streams as seen on maps of suitable scale. Streams which form on newly raised coastal plain beds develop a distinctive pinnate (featherlike) pattern characterized by long, narrow drainage basins, parallelism of main streams with their tributaries and acute angled junctions of tributaries to the main streams. If coastal plain beds once extended significantly further inland than they do at present, the pinnate patterns of streams which formed on these now vanished beds should be still preserved on the older rocks of the Piedmont inland from the coastal plain, since the streams in eroding away the coastal plain beds would not lose their basic pinnate pattern.

"Some indication of once extensive presence of coastal plain beds far inland from their present area of outcrop was found in the southern states in the generally pinnate patttern of the Savannah River. Farther north, however, pinnate patterns in streams of the Piedmont could be found only ten miles inland from the coastal plain margin at the Potomac and Susquehanna Rivers.

"The possibility still remained, however, that coastal plain beds had once extended far inland over the Pennsylvania Appalachian mountains as deduced by Douglas Johnson, but the pinnate pattern of streams superposed from this coastal plain cover had been removed by post-Cretaceous erosion and adjustment of streams to weak rock zones in the Pennsylvania Appalachians.

"The next procedure in the investigation was to study courses of the major rivers in the folded Appalachians of Pennsylvania. If certain of the transverse segments of these rivers could not be explained by normal processes of stream erosion in folded mountains then it would indeed be necessary to postulate superposition of these rivers from a Cretaceous coastal plain cover as held by Johnson. If normal processes could explain the transverse courses, Johnson's theory of coastal plain superposition would be necessary.

"It was found that west of Kittatinny Mountain, the eastermost of the Appalachian ridges, the principles of adjustment of streams to folded rocks enunciated by Davis in 1889 could adequately and simply explain the transverse courses of the major rivers, as well as minor drainage lines in the area. Davis demonstrated that the transverse drainage across the Nittany arch could have been due to "inheritance" or superposition

from a conformable cover. The transverse drainage of the Anthracite Basins could be due to inversion of relief. The courses of the major rivers across Kittatinny Mountain and so-called Reading Prong (South Mountain, Schooley Mountain, Ramapo Mountains uplift) was not adequately explained by Davis, nor was the course of the Susquehanna across Second Mountain, Peters Mountain, Berry Mountain and Buffalo Mountain north of Harrisburg. It was found, however, that modification of Davis' theory permitted even these puzzling stream courses to be explained in the light of normal erosional processes.

"The new theory of origin of drainage on the north Atlantic slope as modified from Davis' earlier theory is as follows. During the lower and middle Triassic, drainage was still northwestward across the present Appalachian mountains in courses whose position still remain unknown. In upper Triassic time the Atlantic seaboard was riven by long faults which dropped great segments of the earth's crust down in long fault troughs. One such trough is the Newark Basin, which extends from New York to Virginia. A great southeast-facing fault scarp rose along the western border of the Newark trough in the paths of the northwest-flowing streams and diverted them in mid-course to new paths along the northeast-southwest axis of the through.

New streams formed in turn on the face of the fault scarp and they vigorously eroded headward across the Reading Prong and Kittatinny Mountain aided by their youth and their low base level which was the floor of the subsiding basin. That such new streams as these actually did so penetrate back west of Kittatinny Mountain has been shown by the present author in an earlier paper. He described stream deposits of upper Triassic age still preserved along the front of the old western border fault of the Triassic Newark basin. These contain gravels derived from Paleozoic beds which now outcrop northwest of Kittatinny Mountain. Near the end of upper Triassic time erosion of the highlands southeast of the Newark fault trough so lowered them in altitude that stream deposits in the trough finally rose up and over the eastern highlands. This permitted the southeast flowing streams coming from the Appalachians northwest of the trough to flow unhindered southeastward to the sea.

"Since upper Triassic time the southeast flowing streams which were born in the manner previously described slowly adjusted their paths northwest of Kittatinny mountain into the courses which they possess at present."

NEW HEBRIDES AREA SITE OF BIG QUAKE

WASHINGTON, Dec. 5 (Science Service) — The vicinity of the New Hebrides Islands in the Pacific has been spotted as the location of a world-shaking earthquake of December 2 that gave a big jolt to seismographs. Records collected in part by Science Service from American, Samoan and Japanese stations allowed the determination of location by U. S. Coast and Geodetic Survey experts. Rated 7.6 on the earthquake intensity scale upon which 8.5 is tops, the quake may have caused tidal waves that caused damage.

COVER PHOTO

Two unusual trilobite specimens — (top) dorsal view of *Ceratocephala pygidium* (x6); (bottom) antero-dorsal view of *Ceratocephala cranidium* (x4) — provide this month's cover photo. Courtesy of H. B. Whittington. (See "New Trilobites Described," p. 14.)

Earth Science Abstracts

[Selected articles on the earth sciences, appearing in current scientific publications, are abstracted here for the convenience of our readers.]

PHYSICAL GEOLOGY

BEDROCK SOURCE OF TILLS IN SOUTHWESTERN ONTARIO. Conrad P. Gravenor. *Am. Jour. Sci.*, v. 249, no. 1, p. 66-71, Jan. 1951. "It has been found that the heavy mineral content of tills has been largely derived from crystalline rocks. The amount of light minerals of crystalline origin which must accompany the heavy minerals can be approximated. Hence, the amount of crystalline-rock material in the finer fractions of till can be established. The results indicate there is more such material in the sand and silt than in the gravel size."

BLUE RIDGE FRONT — A FAULT SCARP. William A. White. *Geol. Soc. Am. Bull.*, v. 61, no. 12, pt. 1, p. 1309-1346, Dec. 1950. "The present Blue Ridge scarp seems to have been produced by a late Tertiary normal fault — the Blue Ridge fault. Evidence of its existence can be found along an almost straight line extending about 700 miles from the vicinity of Gainesville, Georgia, to northwestern New Jersey. Throughout much of its length, the Blue Ridge border fault seems to have utilized pre-existing structures of an older Triassic fault zone which borders the Blue Ridge scarp on the east . . ."

INTENSIVE FROST ACTION ALONG LAKE SHORES. Stephen Taber. *Am. Jour. Sci.*, v. 248, no. 11, p. 748-793, Nov. 1950. "The gravel on beaches in the Finger Lake district of New York is mostly limestone, and it is derived from the boulder clay that blankets much of the region. On most beaches the cobbles are angular to subangular, because they are being ruptured by frost action faster than the fragments can be rounded by waves. Water, to feed growing ice crystals which cause rupture, can be drawn into dense-textured, limestone cobbles embedded in wet clay; for water in fine-grained soils and rocks can be undercooled in the immediate vicinity of ice crystals. Coarse-textured rock, such as sandstone, and dense-textured limestones resting on gravel are seldom broken by freezing, and, therefore, become well rounded. Since water occupying the large voids of sandstone and gravel freezes readily, it cannot be drawn up to ice crystals growing in small voids at slightly lower temperatures."

SANDSTONE SPINDLES. K. M. Hussey and B. A. Tator. *Am. Jour. Sci.*, v. 248, no. 10, p. 734-740, Oct. 1950. "Sandstone spindles, a peculiar feature of weathering, are found in restricted areas of the Dawson arkose (Eocene) outcrop at Corral Bluffs near Colorado Springs, Colorado. These are relatively small, spindle-shaped structures occurring in closely spaced, parallel arrangement in the surface of the exposure. They result from decementing activity by groundwater solutions which develop zones of weakness along planes of crossbedding and jointing. Removal of the material made friable in this manner leaves the more firmly cemented portions as spindle-shaped protuberances in the face of the outcrop."

THREE CRITICAL ENVIRONMENTS OF DEPOSITION, AND CRITERIA FOR RECOGNITION OF ROCKS DEPOSITED IN EACH OF THEM. John Lyon Rich. *Geol. Soc. Am. Bull.*, v. 62, p. 1-10, Jan. 1951 "This paper records an attempt to develop criteria by which rocks formed in the unda, clino, and fondo environments can be

recognized and differentiated. Rocks formed in the unda environment — that lying above wave base — show features produced by wave and current agitation peculiar to that environment. These are: distinctive wavy bedding, cross-bedding, ripple marks, coarse texture, and sparsity of clay-sized material, Rocks formed in the clino environment — that comprising the slope from wave base down to the floor of the water body — show regular, thin interstratifications of silt — and clay-sized material, and aligned flow-markings and flute casts and other flowage phenomena indicating deposition on an inclined surface. They are generally, but not always, free from ripple marks and other indications of agitation of the water, other than that of subaqueous sheet flow believed to be caused by density currents. Rocks formed in the fondo environment — that representing the generally flat floor of the water body — are fine grained, with even, generally massive bedding and are generally free from flow markings, ripples, or other evidences of agitation of the water, though exceptionally, ripple marks may be present. Clay and oozes are characteristic. Reconnaissance application of these criteria proves their pertinence and value. Establishment and perfecting of such criteria will make it possible to read in the rocks the history of the paleogeographic environment at the time of their deposition much more fully and accurately than has heretofore been possible."

HISTORICAL GEOLOGY

EARLY CRETACEOUS MAMMALS FROM NORTHERN TEXAS. Bryan Patterson. *Am. Jour. Sci.*, v. 249, no. 1, p. 31-46, Jan. 1951. "A new triconodont, *Astronoconodon denisoni*, based on lower jaws, and an undetermined mammal, represented by an incomplete humerus, are described from a locality in the upper part of the Trinity Sand, near Forestburg, Montague County, Texas. This is the first locality yielding Early Cretaceous mammals found in America and the second in the world . . . The specimens were found, accompanied by numerous fragmentary remains of fishes, frogs and reptiles, in small pockets, believed to have been laid down under near-shore conditions . . ."

TREE TRUNKS PRESERVED IN A VOLCANIC FLOW IN NORTHERN CAMEROONS. Herbert P. T. Hyde. *Am. Jour. Sci.*, v. 249, no. 1, p. 72-77, Jan. 1951. "An unusual occurrence of casts of tree trunks preserved in a Tertiary flow of olivine basalt is described from the French Cameroons, the mode of preservation is discussed, and the few hitherto known phenomena of a similar nature are described. Finally, a record of the microscopic examination of the material is given."

ECONOMIC GEOLOGY

GEOLOGY OF THE BROKEN HILL ORE DEPOSIT, BROKEN HILL, N. S. W., AUSTRALIA, J. K. Gustafson, H. C. Burrell, and M. D. Garretty. *Geol. Soc. Am. Bull.*, v. 61, no. 12, pt. 1, p. 1369-1438, Dec. 1950. "The lead-silver-zinc ore deposit of Broken Hill, New South Wales, is among the great ore deposits of the world because of its size, richness, and continuity. Up to the end of 1946 approximately £50,000,000 in dividends had been won from recoverable metals worth £210,500,000 gross contained in 63,800,000 tons of ore. The deposit is a hypothermal deposit of Pre-cambrian age resulting from the selective replacement of two closely adjacent, tightly and complexly folded stratigraphic rock layers..."

PROSPECTING FOR ZINC USING SEMIQUANTITATIVE CHEMICAL ANALYSES OF SOILS. R. B. Fulton. *Econ. Geol.*, v. 45, no. 7, p. 654-670. "A field method of semiquantitative chemical analysis of soil from zinc is applied to prospecting for zinc in soil-

covered areas. Fifteen hundred soil samples taken over known ore bodies and over barren ground have been analyzed by the dithizone method. The relation of zinc content of the soil to the underlying ore bodies has been studied including consideration of the influence of depth of ore, nature of soil cover, mineralization in rock above ore, faults and fractures, and ground water circulation . . . The method shows considerable promise as a tool for discovery of ore deposits masked by soil."

NORMAN L. BOWEN WINS ROEBLING MEDAL

Dr. Norman L. Bowen, Geophysical Laboratory, Carnegie Institution of Washington, has been awarded the Roebling Medal of the Mineralogical Society of America. The Roebling medal is for meritorious achievement in the mineralogical sciences and constitutes the highest honor bestowed by the society.

This year's award is the tenth since the medal was established in 1937. Presentation was made at the society's annual luncheon by Prof. Arthur F. Buddington, Princeton University.

For his outstanding application of physical chemistry to rocks and minerals, Dr. Bowen has previously received the Bigsby Medal of the Geological Society of London in 1931, the Penrose Medal of the Geological Society of America in 1941, the Miller Medal of the Royal Society of Canada in 1943, and the Wollaston Medal of the Geological Society of London in 1950. He was president of the Mineralogical Society of America in 1937 and of the Geological Society of America in 1946.

"For the first time" Prof. Buddington said, "the Roebling award goes to a physicochemical petrologist and mineralogist, Dr. N. L. Bowen, whose researches have been based preeminently on quatitative experimental physicochemical work, a field which has been exclusively developed in the present century. Dr. Bowen also further exemplifies a peculiarly significant 20th century development, a Canadian in the tradition of A. C. Lawson and R. A. Daly, who has crossed to the United States and in addition to so outstandingly advancing the science has also helped to educate our students."

DR. NORMAN L. BOWEN

Dr. Bowen gained recognition as a leader in science early in his career. In 1912 he entered the Geophysical Laboratory and in 1915 at the age of 28 years he became internationally known through publication by Princeton University press of his book, "The Evolution of Igneous Rocks" a work which is still a standard for all students of this subject.

"In this work" Bowen has expounded the role of fractional crystallization as the major explanation for the diversity of origin of igneous rocks," Prof. Buddington disclosed. "He has brought forward an overwhelming mass of experimental data developed by himself and his colleagues of the Carnegie Geophysical Laboratory, and has exercised the greatest of ingenuity and skill in showing how the data and principles might apply

in support of his thesis. He is recognized as a most doughty opponent in the continuing warfare between certain interpretations based upon laboratory data and conflicting interpretations based on field data.

"One of the great merits of his work and one for which all petrologists are profoundly grateful is the effort which he has made to give examples of the application of the experimental physico-chemical data and principles to petrological problems. In this connection he has diligently sought to visit the classic localities for problems of igneous rocks. He has personally studied the Bushveld of South Africa, the alkalic lavas of East Africa, the peridotites of Skye, the Adirondack and Canadian anorthosites, and there are few noted petrologic localities in the U. S. which he has not visited in continuing his own education."

HARVARD GEOPHYSICIST WINS ARTHUR L. DAY MEDAL

Dr. Francis Birch, professor of geology at Harvard University, received the 1950 Arthur L. Day medal of the Geological Society of America. Presentation was made by Dr. Leason H. Adams, of Carnegie Geophysical Laboratory, Washington, D. C.

The medal is a memorial to Dr. A. L. Day who was in large measure responsible for the establishment of the Geophysical Laboratory and was its first director. His life work set a high standard in the quantitative approach to geology and the medal is given "in recognition of outstanding contributions in the application of chemistry and physics to the solution of geologic problems."

Commenting on the award to Dr. Birch, Dr. Adams stated that it was the desire of the donor that the medal be a token of outstanding achievement and an inspiration for further effort, rather than a reward at the close of a distinguished career. Expressed another way, the award is given in recognition of achievement on a rising curve of contributions rather than as a reward for mass achievement on a flattened curve of retirement.

Professor Birch received his B. S. at Harvard in 1924, his master degree in 1929 and Ph.D. in 1932. He was associated with the New York Telephone Company for two years from 1924-26 and has been connected with Harvard ever since, achieving the rank of full professor in 1946.

DR. FRANCIS BIRCH

The author of numerous papers on the properties of materials at high pressures and high temperatures, geothermal studies and elasticity, Professor Birch served with the Office of Naval Research with the rank of Commander during the war years, and for a time joined the staff of the Radiation Laboratory at Massachusetts Institute of Technology.

Professor Birch is the third person to receive this medal. In 1948 it went to Dr. George W. Morey, and in 1949 to Professor W. Maurice Ewing of Columbia University.

WATER RESOURCES – DECEMBER 1950

General high water and scattered floods prevailed during the month of December throughout eastern Canada, the Northeastern States and south to the Ohio Valley to make this region's water record noteworthy, according to the latest *Water Resources Review*.

Throughout the Northwest the story was similar: high water and scattered floods. Conditions looked good in most of California for ample water supplies in the spring, except that in Southern California and Arizona drought conditions continued. There was a new record low runoff for December in Santa Ysabel Creek near Mesa Grande and in Arizona almost all records for minimum flow were broken during the last three months of the year. Storage in major reservoirs continued to decline, with the San Carlos Reservoir on the Gila River practically empty.

In New England relatively heavy rains during the first half of December, aided by high streamflow and ground-water levels which prevailed at the end of November, produced a runoff average of about 180 percent of normal at four index streams. In Maine, record or near-record floods occurred in many streams in the eastern part of the State, but little damage was done except where washouts on main-line railroads halted traffic.

Ground-water levels in New Hampshire, Vermont, Massachusetts and Rhode Island continued to rise during the past month. Rises ranged from less than a foot in parts of Rhode Island, Massachusetts and New Hampshire to a maximum of almost six feet recorded in a well at Portsmouth, Rhode Island.

New Books

All books listed here are deposited in the Library of The Earth Science Institute and may be borrowed by the members. Books marked with an asterisk may be purchased through The Earth Science Publishing Co., Revere, Mass.

*GEM HUNTER'S GUIDE. 2nd Edition. Russell P. MacFall. 1951. iv, 196 p., 8 pls.; $3.00 (Science & Mechanics Publishing Co., Chicago).

This interesting little book should do much toward promoting a growth in the number of amateur gem and mineral collectors. The first edition was sold out promptly, and this new and greatly enlarged book promises to have the same fate in store for it. Lists of locations in which gem materials have been found and a listing of the locations for each gem material form the major part of the book. Other sections include tables on the characteristics of important gem stone materials, separate chapters on diamonds and pearls, fluorescent minerals, sources of information, and separate chapters on American diamonds and pearls. Many of the localities listed have been obsolete for many years or afford very little in the way of specimens.

*MARINE GEOLOGY. Ph. H. Kuenen. 1950. x, 568 p., 2 pls., 246 figs.; $7.50 (John Wiley & Sons, N. Y.).

In contrast to Shepard's *Submarine Geology*, which emphasizes geomorphology and field techniques, and other recent works which deal mainly with geophysics, geography, or oceanography, in this new volume Professor Kuenen has summarized present knowledge of the geology of the sea, with emphasis on problems and relations rather than descriptive material and data. The author has given special attention to coral reefs, submarine canyons, and the Indonesian deep-sea depressions. An extensive bibliography follows each chapter. The book is well illustrated, with clear line drawings, charts, and maps. Concise definitions and lucid discussions of various terminologies add to the value of this excellent work.

1940 E. W. SCRIPPS CRUISE TO THE GULF OF CALIFORNIA. Charles A. Anderson, J. Wyatt Durham, Francis P. Shepard, M. L. Natland, and

Roger Revelle. 1950. 364 p., 76 pls., 28 figs.; $6.50 (Memoir 43, Geological Society of America, N. Y.).

The purpose of this expedition was to study the geologic processes which are or have been active in the Gulf of California. The five parts of the volume consist of papers on the geology of the island and neighboring land areas by Anderson; the megascopic paleontology and marine stratigraphy by Durham; the submarine topography of the Gulf, including a series of charts and a glossary of place names, by Shepard; a report on the Pleistocene and Pliocene sedimentation and oceanography by Revelle.

Other Publications Received

SILICA SAND FROM SOUTH-CENTRAL KANSAS FOR FOUNDRY USE. Kenneth E. Rose. 1950. 20 p., 2 figs.; $0.10 (Bull. 86, Pt. 4; State G. S. of Kansas, Lawrence). Concerned primarily with the Cheyenne Sandstone deposits and its characteristics.

ORIGIN AND ENVIRONMENT OF THE TONGANOXIE SANDSTONE IN NORTHEASTERN KANSAS. Thomas W. Lins. 1950. 36 p., 1 pl., 3 figs.; $0.10 (Bull. 86, Pt. 5; State G. S. of Kansas, Lawrence). The origin, environment of deposition, and stratigraphic relations of the sandstone are presented with the results of detailed sedimental and stratigraphic studies bearing on these problems.

CONTRIBUTIONS TO THE KNOWLEDGE OF THE CHEMISTRY OF THE RADIOACTIVE MINERALS OF FINLAND. Lauri Lokka. 1950. 76 p., 7 figs.; 100 Markaa (about $0.43). (Bull. 149 de la Commission Geol. de Finlande; Geologinen Tutkimuslaitos, Helsinki). The chemistry of the following minerals is presented: gadolinite and allanite from Southwestern Finland; allanite, monazite, nuolaite, lloranskite, and wiikite from Impilahti; wiikite from Salla, E. Lapland; and monazite from Ivalojoki River, N. Lapland.

The BOOK SHELF

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New Books

The following books were not listed in our complete catalog of books on the earth sciences, which appeared in the Earth Science Digest from June 1949 to January 1950.

THIS EARTH OF OURS by C. W. Wolfe. 1950. 384 pp., 239 figs.	$ 5.00
THE CAVE BOOK by Charles E. Hendrix. 1950. 68 pp., 34 figs.	1.00
STRUCTURAL PETROLOGY OF DEFORMED ROCKS by H. W. Fairbarn. 1949. 344 pp., 213 figs.	12.50
REBELLIOUS RIVER by J. P. Kemper. 1949. 279 pp., 7 figs.	6.00
APPLIED SEDIMENTATION edited by Parker D. Trask. 1950. 707 pp., 114 figs.	5.00
GRASSLAND HISTORICAL STUDIES by James C. Malin. Vol. I: Geology and Geography. 1950. 377 pp., 5 figs.	2.50
GEOCHEMISTRY by Kalervo Rankama and Th. G. Sahama. 1950. 912 pp., 50 figs.	15.00
INTRODUCTION TO THEORETICAL IGNEOUS PETROLOGY by Ernest E. Wahlstrom. 1950. 366 pp., 155 figs.	6.00
APPLIED HYDROLOGY by Ray K. Linsley Jr., Max A. Kohler, and Joseph L. H. Paulhus. 1949. 689 pp., 329 figs.	8.50
CRYSTALS AND X-RAYS by Kathleen Lonsdale. 1949. 199 pp., 13 pls., 138 figs.	3.75
GEOLOGY APPLIED TO SELENOLOGY — IV: THE SHRUNKEN MOON by J. E. Spurr. 1949. 207 pp., 36 figs.	4.00
A NEW THEORY OF HUMAN EVOLUTION by Sir Arthur Keith. 1949. 451 pp., 1 fig.	4.75
INTRODUCTION TO COLLEGE GEOLOGY by Chauncey D. Holmes. 1949. 429 pp., 312 figs.	4.00
THE ART OF THE LAPIDARY by Francis J. Sperisen. 1950. 382 pp., 1 pl., 406 figs.	6.50
GEOLOGY FOR ENGINEERS by Joseph M. Trefethen. 1949. 620 pp., 242 figs.	5.75
HYDROLOGY by C. O. Wisler and E. F. Brater. 1949. 419 pp., 132 figs.	6.00
NORTHWEST GEM TRAILS by H. C. Dake. 1950. 80 pp., 14 figs.	2.00

Is there a book relating to the earth sciences which you need and which was not listed in our catalog? If so, why not write to us? We can obtain for you practically any "in-print" book published.

The Book Shelf

The Earth Science Publishing Company Revere, Mass.

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